

# Nucleon Resonance Electrocouplings from the CLAS Data on Exclusive Meson Electroproduction off Protons

Victor I. Mokeev<sup>1,a, b</sup>, Inna G. Aznauryan<sup>c</sup>, and Volker D. Burkert<sup>a</sup>

<sup>a</sup>*Jefferson Lab, USA*

<sup>b</sup>*Skobeltsyn Nuclear Physics Institute at Moscow State University, Russia*

<sup>c</sup>*Yerevan Physics Institute, Armenia*

$\gamma_v NN^*$  transition helicity amplitudes (electrocouplings) of several prominent excited proton states are determined for the first time in independent analyses of  $\pi^+n$ ,  $\pi^0p$ , and  $\pi^+\pi^-p$  electroproduction off protons. Analysis of  $\pi^+\pi^-p$  electroproduction has extended considerably information on electrocouplings of high lying  $N^*$  states, which decay preferentially to the  $N\pi\pi$  final states.

## 1 Introduction

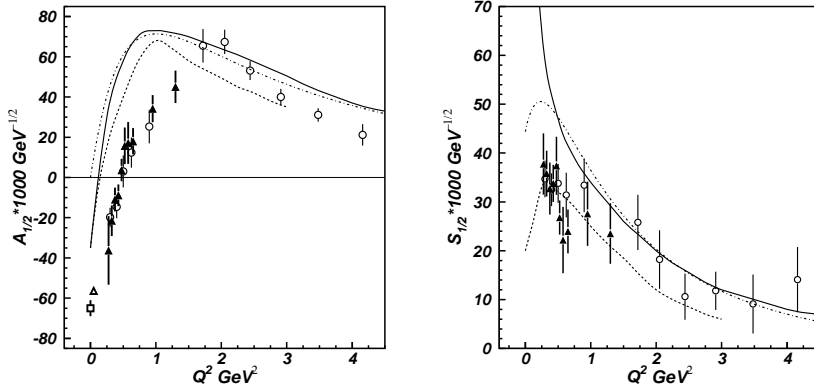
The studies of nucleon resonance structure from the data on different exclusive meson electroproduction channels off nucleons represent an important direction in the  $N^*$  program with the CLAS detector with the primary objective of determining electrocouplings of all prominent excited proton states in a wide area of photon virtualities  $Q^2 < 5.0 \text{ GeV}^2$  [1]. In this paper we present the results on  $N^*$  electrocouplings obtained in independent analysis of  $\pi^0p$ ,  $\pi^+n$ , and  $\pi^+\pi^-p$  electroproduction off protons.

## 2 Evaluation of $N^*$ electrocouplings from exclusive meson electroproduction data

The  $\pi^+n$ ,  $\pi^0p$ , and  $\pi^+\pi^-p$  exclusive channels are major contributors to meson electroproduction off protons in  $N^*$  excitation region. They are sensitive to  $N^*$  contributions and account for  $\approx 90\%$  of meson electroproduction cross section. Non-resonant contributions in these channels are different, while  $N^*$  electrocouplings remain the same, since resonance electroproduction and hadronic decay amplitudes are independent. Therefore, consistent values of  $N^*$  electrocouplings determined from different major meson electroproduction channels strongly support a reliable extraction of these fundamental quantities.

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<sup>1</sup>mokeev@jlab.org



**Figure 1:** Electrocouplings of the  $P_{11}(1440)$  resonance determined in independent analyses of the CLAS data on  $N\pi$  (circles) and  $\pi^+\pi^-p$  (triangles) electroproduction off protons. Square and triangle at  $Q^2=0$  correspond to RPP [8] and the CLAS  $N\pi$  [9] photoproduction results, respectively. The results of relativistic light-front quark models [10,11] are shown by solid and dashed lines, respectively. Results of the covariant valence quark-spectator diquark model [12] are shown by the dashed dotted line.

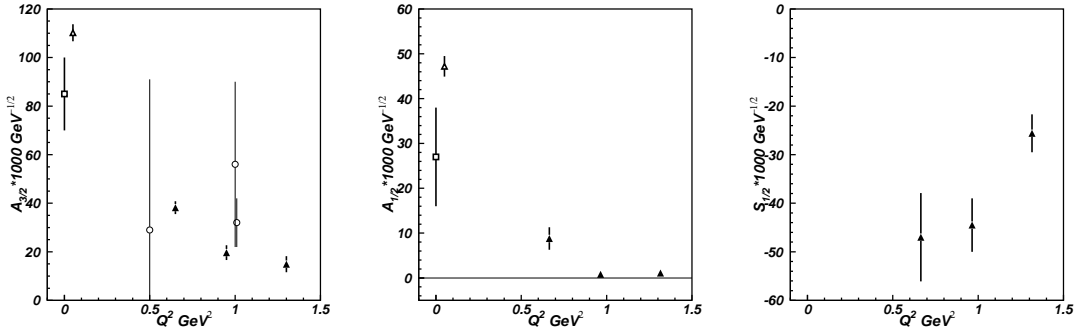
The CLAS data considerably extended information on  $\pi^+n$ ,  $\pi^0p$  electroproduction off protons. A total of nearly 120000 data points on unpolarized differential cross sections, longitudinally polarized beam asymmetries, and longitudinal target and beam-target asymmetries were obtained with almost complete coverage of the accessible phase space [2]. The data were analyzed within the framework of two conceptually different approaches: a) the unitary isobar model (UIM) and b) a model, employing dispersion relations [3,4]. The two approaches provide good description of the  $N\pi$  data in the entire range covered by the CLAS measurements:  $W < 1.7$  GeV and  $Q^2 < 5.0$  GeV<sup>2</sup>, resulting in  $\chi^2/\text{d.p.} < 2.0$ .

Nine independent one-fold-differential and fully-integrated  $\pi^+\pi^-p$  electroproduction cross sections of protons are determined from the CLAS measurements [5,6] in 131 bins of  $W$  and  $Q^2$  in a mass range  $W < 2.0$  GeV, and with photon virtualities of  $0.25 < Q^2 < 1.5$  GeV<sup>2</sup>. Analysis of these data within framework of the meson-baryon JM reaction model [7,14] allowed us to establish all essential contributing mechanisms from their manifestation in the measured cross sections. Reasonable data description makes it possible to provide a reliable separation between resonant and non-resonant contributions needed for extraction of  $N^*$  electrocouplings from  $\pi^+\pi^-p$  electroproduction data.

### 3 Results and discussion

Electrocouplings of the  $P_{11}(1440)$ ,  $D_{13}(1520)$  states have become available from independent analyses of the CLAS data on  $\pi^+n$ ,  $\pi^0p$  ( $Q^2 < 5.0$  GeV<sup>2</sup>), and  $\pi^+\pi^-p$  ( $Q^2 < 1.5$  GeV<sup>2</sup>)

electroproduction channels [2, 14]. Their values obtained from these major meson electroproduction channels with different non-resonant mechanisms are in a good agreement. As an example, electrocouplings of the  $P_{11}(1440)$  state are shown in Fig. 1. Consistent results on  $N^*$  electrocouplings demonstrate that the reaction models [4, 7, 10] mentioned in the Section 2 provide reliable evaluation of these fundamental quantities. It makes possible to determine electrocouplings of all resonances that decay preferentially to the either  $N\pi$  or  $N\pi\pi$  final states analyzing independently the  $N\pi$  or  $\pi^+\pi^-p$  electroproduction channels.



**Figure 2:** Electrocouplings of  $D_{33}(1700)$  (left) and  $S_{31}(1620)$  (middle and right) resonances from analyses of the CLAS data on  $\pi^+\pi^-p$  [5, 6] and world data [15] on  $N\pi$  electroproduction off protons. Symbols are the same as in Fig. 1.

Preliminary results on electrocouplings of  $S_{31}(1620)$ ,  $S_{11}(1650)$ ,  $F_{15}(1685)$ ,  $D_{33}(1700)$  and  $P_{13}(1720)$  states were obtained from the CLAS  $\pi^+\pi^-p$  electroproduction data [5]. The CLAS results provide accurate data on the  $Q^2$ -evolution of the transverse electrocouplings and the first information on the longitudinal electrocouplings of all the above mentioned excited proton states. Several examples are shown in Fig. 2. A dominance of longitudinal  $S_{1/2}$  electrocoupling is observed in electroexcitation of  $S_{31}(1620)$  state at  $Q^2 > 0.5 \text{ GeV}^2$  (see Fig. 2).

The CLAS results on electrocouplings of prominent resonances stimulated the development of  $N^*$  structure models [16, 17]. The analysis of resonance electrocouplings within the framework of light front [10, 11] and quark-spectator diquark [12] models, complemented by the coupled channel approach [13] demonstrate that the structure of  $N^*$  states in a mass range  $W < 1.6 \text{ GeV}$  is determined by a combined contribution of an internal core of three dressed quarks and an external meson-baryon cloud. The recent studies in the light-front quark model [18] revealed an important role of dynamical mass and structure of dressed quarks in  $Q^2$ -evolution of  $N^*$  electrocouplings. Furthermore, two conceptually different approaches of QCD-Dyson-Schwinger equations [19, 20] and Lattice QCD [21–23] are making progress toward the description of  $N^*$  electrocouplings from the first principles of QCD.

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